# CERES Energy Balanced and Filled (EBAF) TOA Edition 4 Update

**Norman G. Loeb, Wenying Su, Hailan Wang, Cathy Nguyen, David Doelling, Seiji Kato, Fred Rose, Joe Corbett, Lusheng Liang**

Earth Radiation Budget Workshop, October 18-21, 2016
ECMWF, Reading, UK

## EBAF-TOA Ed2.8 (Current Version)

- Essentially a hybrid of:
  - Clouds & ADMs used in CERES SSF Ed2 (same as Ed3)
    - => GEOS 4 (03/2000-12/2007), GEOS 5.2.1 (01/2008-)
    - => MODIS Collection 4 (03/2000-04/2006) & 5 (05/2006-)
  - TOA fluxes determined using Ed3 calibration coefficients
- While input changes have minimal impact on all-sky TOA fluxes, they cause discontinuities in clear-sky TOA fluxes (through scene identification) and all-sky and clear-sky surface radiative fluxes.
- Consequently, there's a spurious trend in TOA Cloud Radiative Effect.
- EBAF-SFC makes adjustments to minimize impact of input changes.

## EBAF-TOA Ed 4.0 (All-Sky)

- Will incorporate all of the Ed4 algorithm improvements:
  - Improved instrument calibration
  - Cloud properties
  - ADMs
  - Time Interpolation and Space Averaging (with hourly GEOs)
  - Will be based upon consistent met assimilation (GEOS 5.4.1), MODIS radiances and aerosols (Collection5, until that gets superseded by C6 in Jan 2017)
  - GMT instead of local time
- TOA fluxes will be constrained using same approach as EBAF Ed2.8 (Argo constraint) but using 10 years of Argo instead of 5 years.
- Will provide some basic MODIS cloud properties ($f$, $\tau$, $p_{eff}$) alongside TOA fluxes on ordering tool.

# CERES EBAF Ed4.0 Empirical Diurnal Corrections

- Use daily SYN1deg & SSF1deg files for 07/2002 – 06/2015 to compute climatological monthly mean ratios of SYN1deg/SSF1deg sorted by:

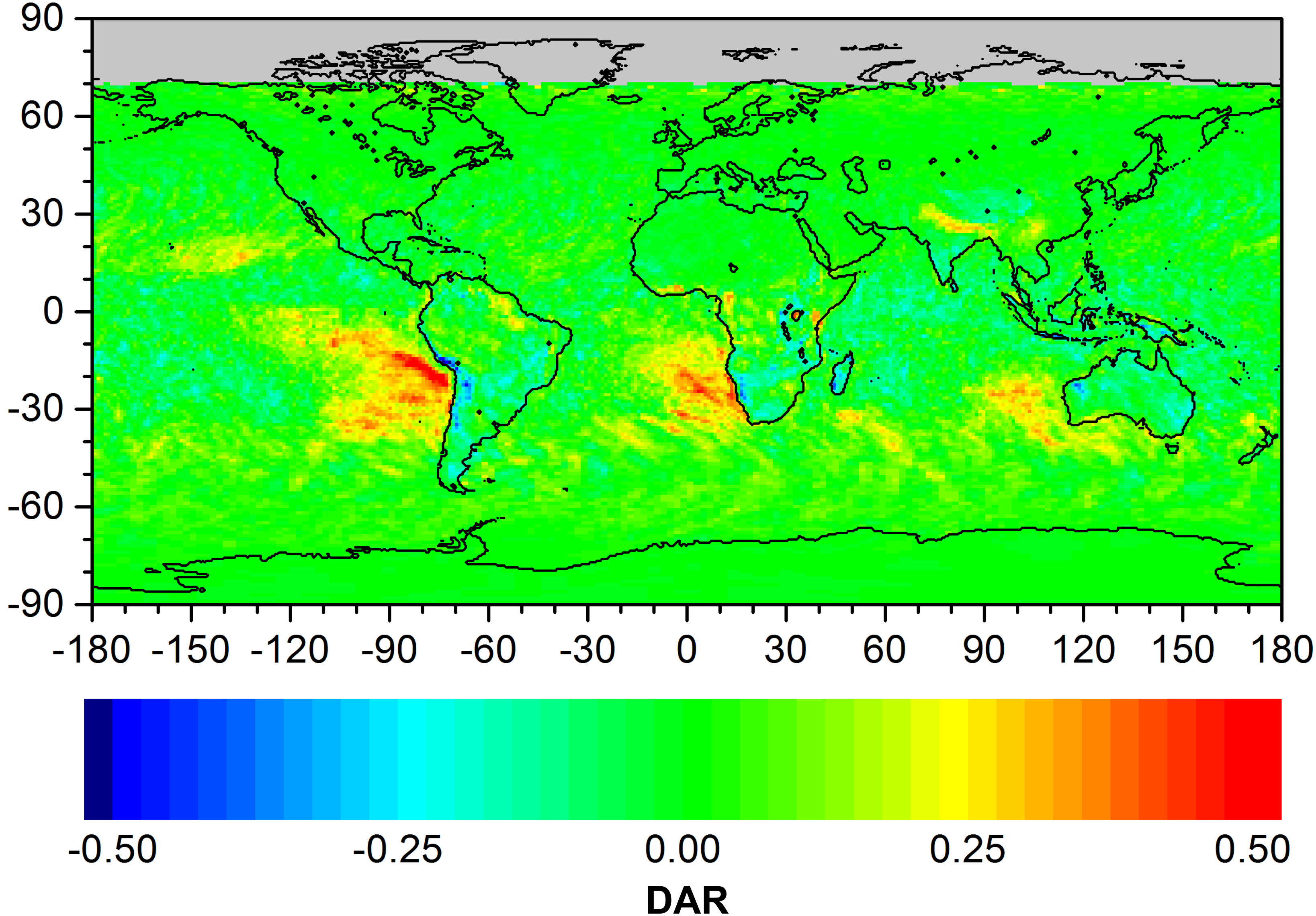
  1) Month (1-12)
  2) Surface Type
     i) Open ocean (No snow). IGBP 17.
     ii) Desert (IGBP 7 or 16)
     iii) Surface types other than open ocean and desert.
  3) Diurnal Asymmetry Ratio (DAR)

$$= \{[F^{SW}(\text{morn}) - F^{SW}(\text{aft})]/12\} / F^{SW}(24\text{h})$$

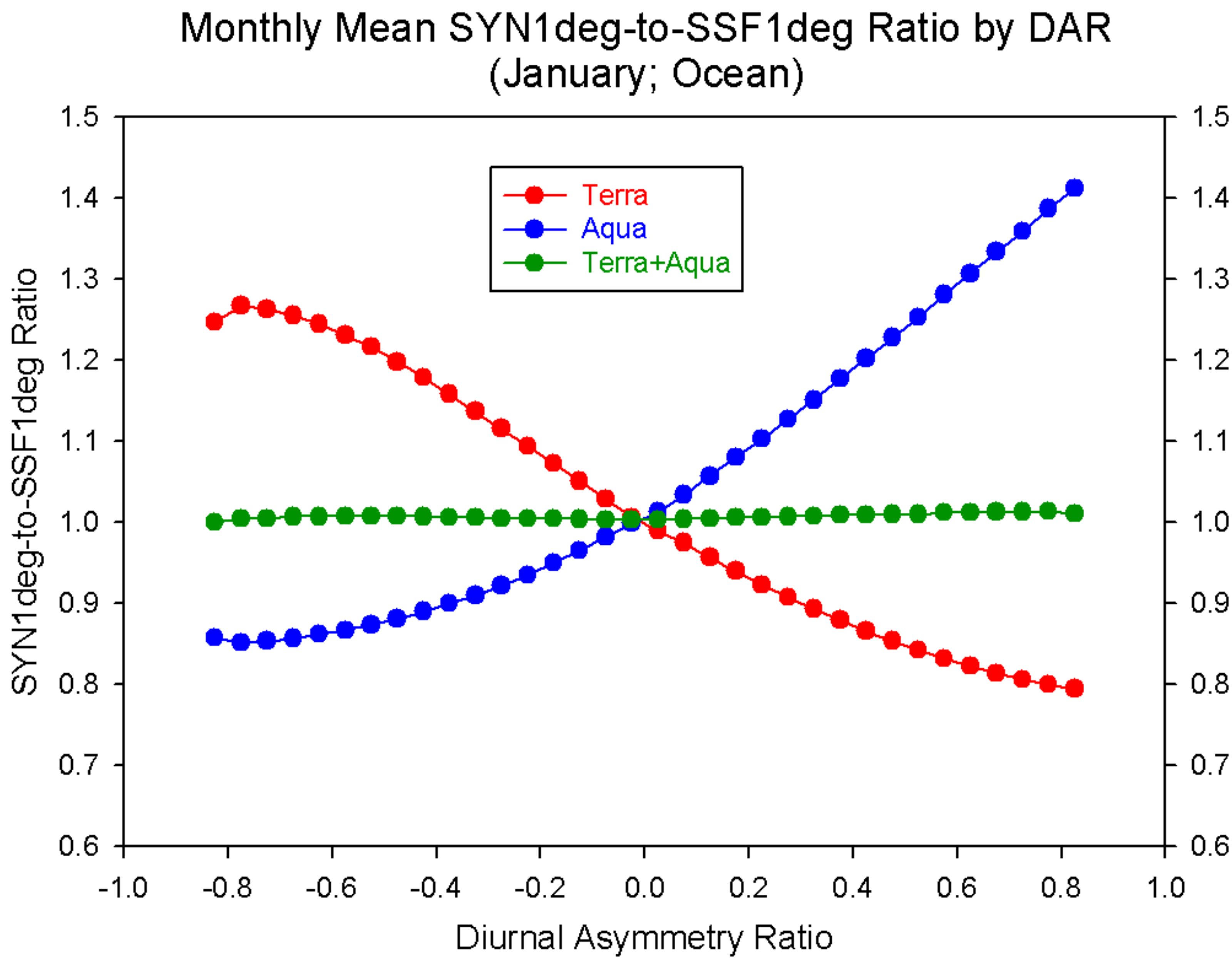
  - Use discrete DAR intervals of width 0.05 [-0.8, 0.8]
- Develop 3 sets of diurnal corrections: Terra SSF1deg, Aqua SSF1deg, and Terra_Aqua SSF1deg.

Application:
- Use the SYN1deg-to-SSF1deg ratios to convert daily mean SSF1deg fluxes to diurnally corrected values ("SYN1deg-Like").
- Average diurnally corrected SSF1deg fluxes to monthly means.

## Diurnal Asymmetry Ratio (DAR)
## (201001)

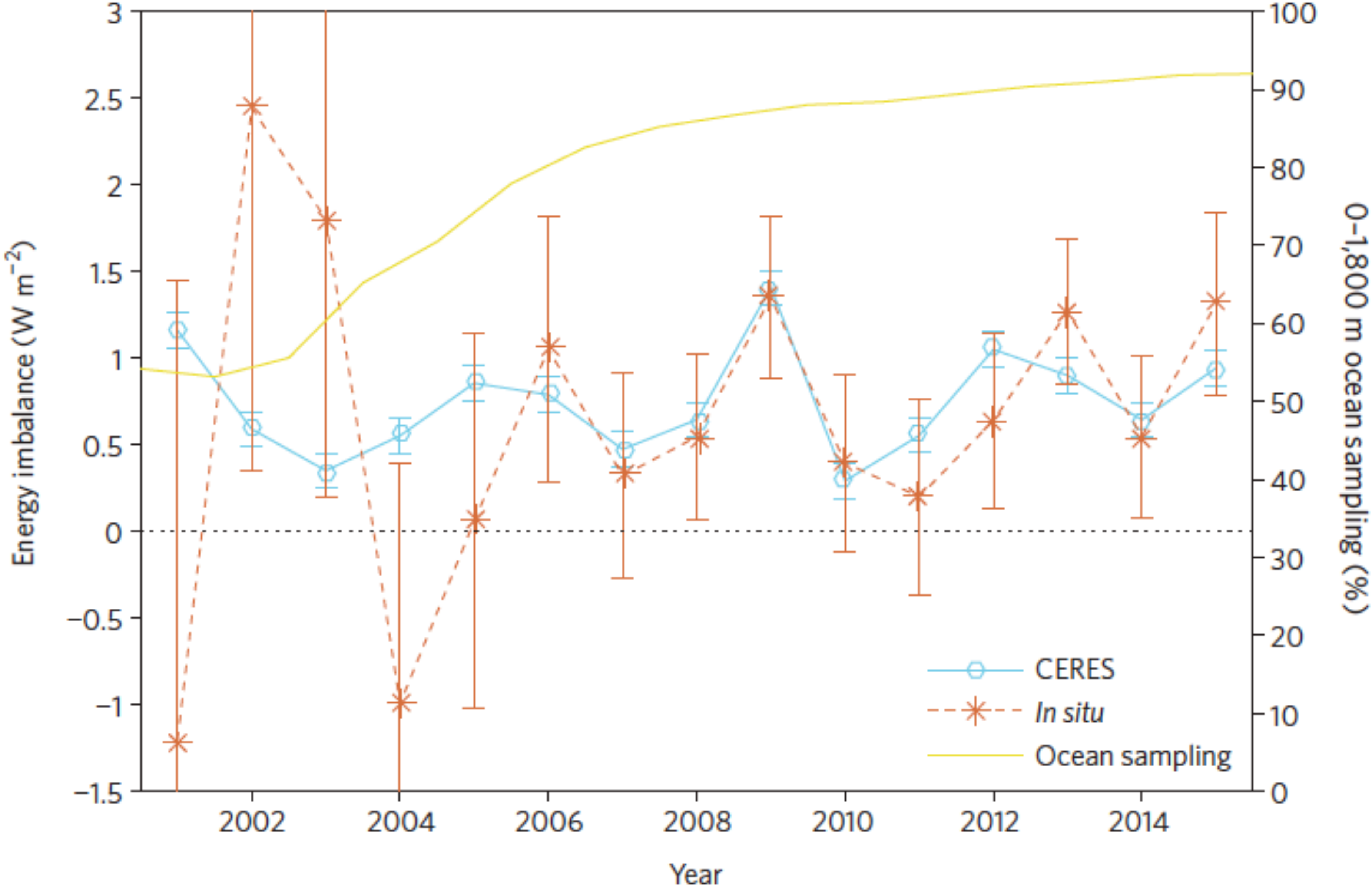



DAR = {[FSW(morn)−FSW(aft)]/12} / FSW(24h)



Monthly Mean SYN1deg-to-SSF1deg Ratio by DAR
(January; Ocean)
Terra
Aqua
Terra+Aqua
SYN1deg-to-SSF1deg Ratio
Diurnal Asymmetry Ratio
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

# Variability in Earth's Energy Imbalance: CERES vs in situ




EEI Average (2001-2015) = 0.71 ± 0.1 Wm$^{-2}$

(Johnson et al. 2016)

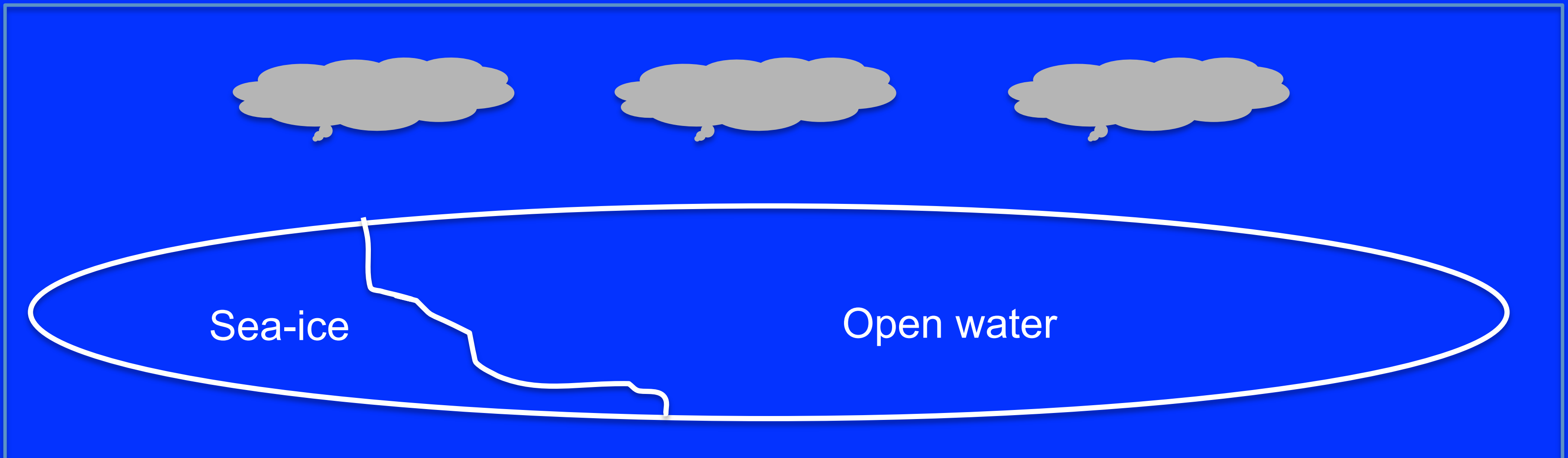
# EBAF-TOA Ed 4.0 (High-Resolution Clear-Sky Fluxes)

- Includes clear-sky fluxes from cloud-free CERES footprints & estimates from clear portions of partly cloudy CERES footprints.

**<u>Ed4 Improvements</u>:**

- Ed4 MODIS cloud mask & CERES ADMs (Ed4 SSF).
- New narrow-to-broadband regressions: use more MODIS bands available in Ed4 CERES SSF.
- Consider only CERES footprints with < 95% cloud fraction.
- Estimate clear-sky fluxes for footprints with partial snow and sea-ice coverage.
- Fix bug found in Ed2.8 SW clear-sky time-space averaging.
    - Ed2.8 erroneously used all-sky directional models (DMs) instead of clear-sky DMs.
- Include clear-sky area weighting of daily mean SW clear-sky TOA fluxes within a region when computing monthly mean clear-sky TOA flux.
- For LW, use equal-area weighting of daily means.
- Based upon MODIS Terra for 2000-2002; MODIS Aqua for 2002-onwards.
    - Aqua water vapor bands more stable in time than for Terra.

# Clear-sky Flux for Partly Cloudy Footprints with Partial Snow/Sea-ice Cover



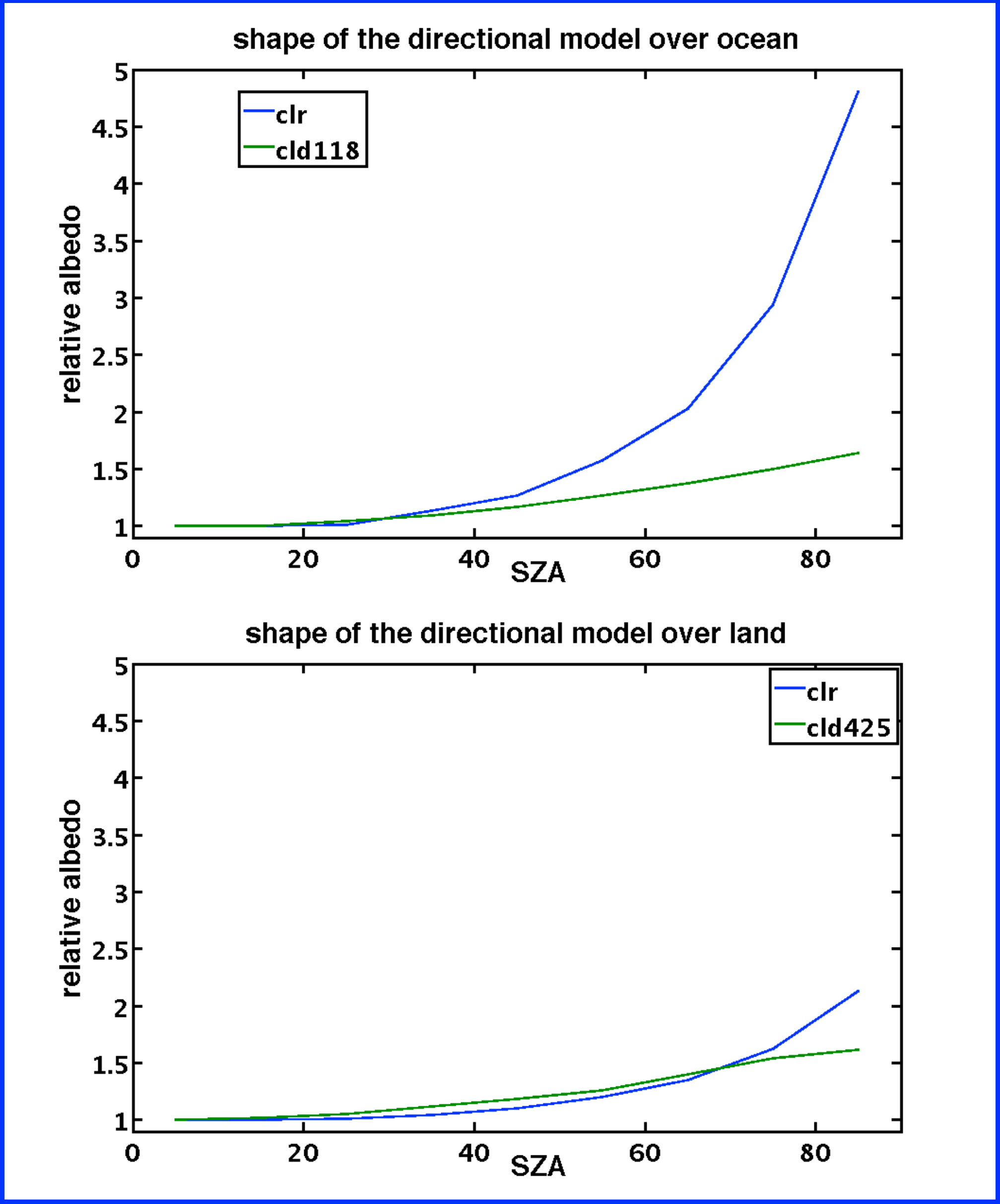

**EBAF Ed2.8**

- Only estimate high-resolution clear-sky flux if FOV is partly cloudy and has 100% sea-ice, 100% open water or 100% land coverage.
  => Excludes many FOVs with high partial sea-ice coverage.
  => Clear-sky SW TOA flux biased low over summertime Arctic Ocean.

**EBAF Ed4.0**

- Estimate high-resolution clear-sky flux if FOV is partly cloudy and partly sea-ice/ water or partly snow/land. Apply both sets of regressions to clear-sky radiances and weight by surface type coverage.
  => Increases clear-sky SW TOA flux over Arctic Ocean compared to Ed2.8.

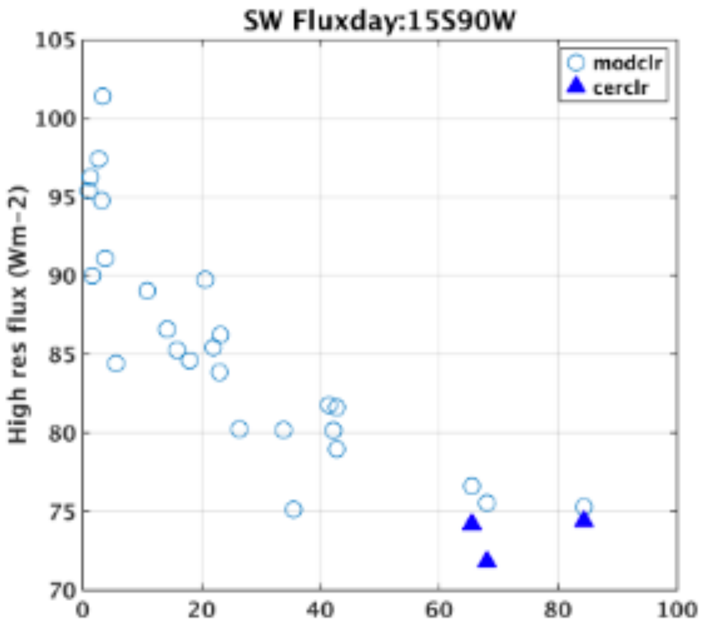
# Influence of Incorrect Specification of Directional Albedo on 24h Average Clear-sky SW TOA flux

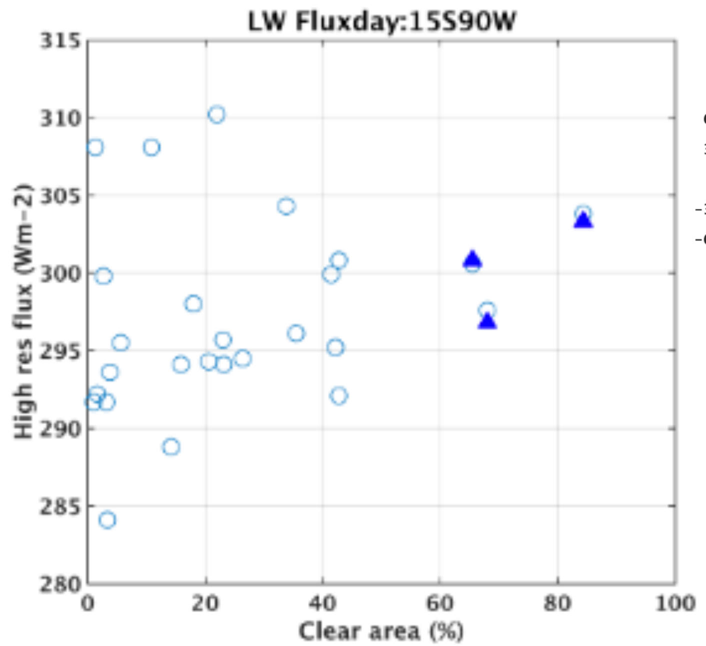


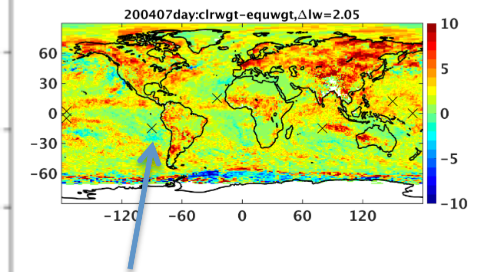

- Ed2.8 erroneously used an average all-sky directional albedo model over a region instead of clear-sky DMs.
- This causes 24h clear-sky SW TOA flux to be underestimated.
- Underestimation is greater over ocean than land.

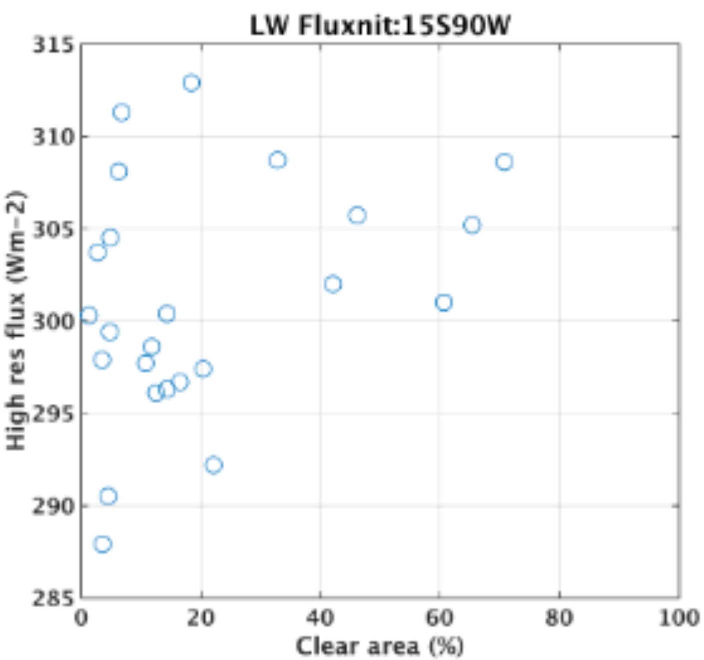
Note: directional albedos based upon CERES TRMM observations.

# Gridbox Daily Mean Clear-Sky SW or LW TOA Flux vs Clear Area Average (**15°S, 90°W**)



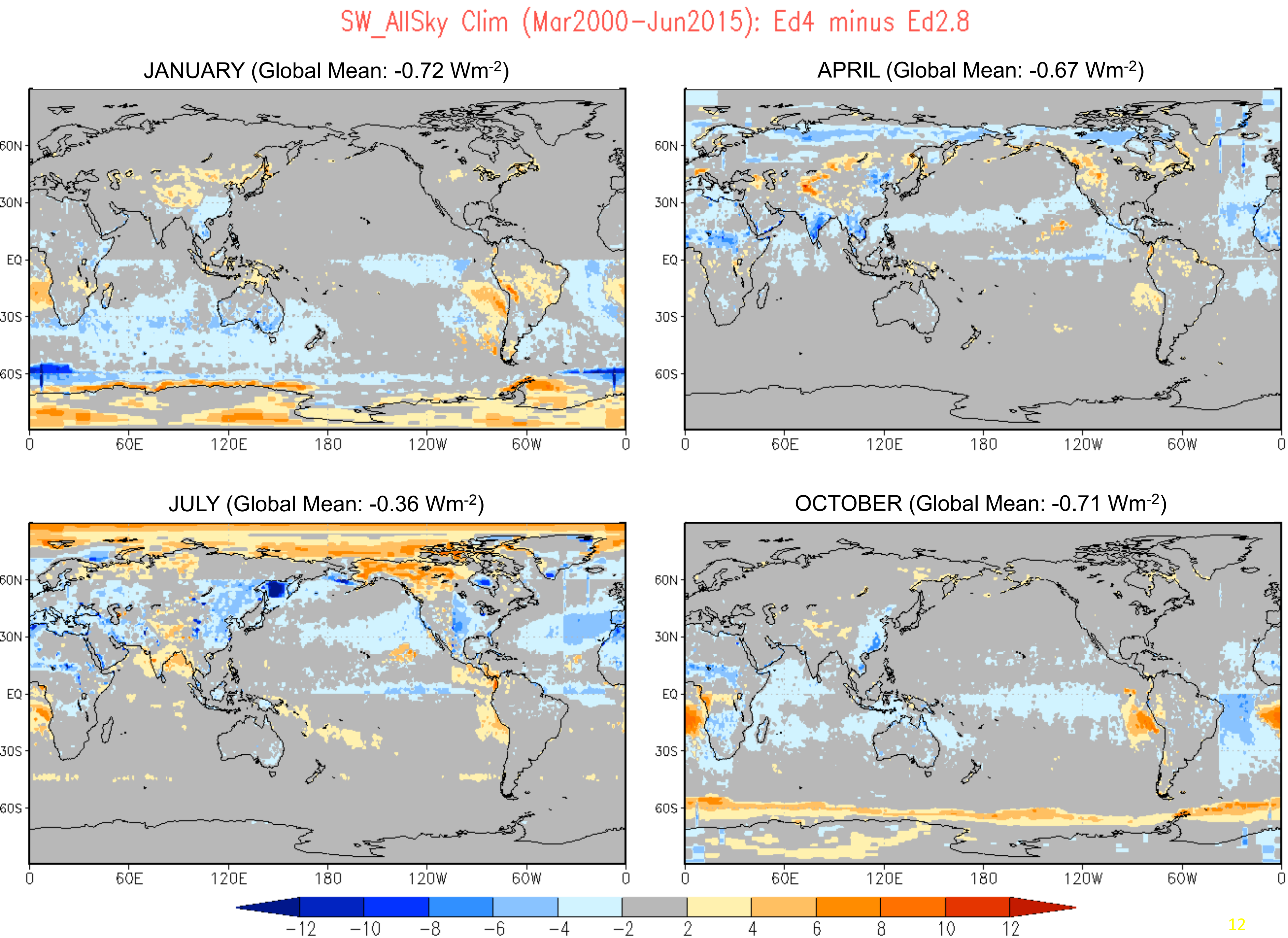

- Hi-Res clear-sky SW TOA flux highly correlated with clear-area fraction.

- Likely cloud contamination (low clouds)

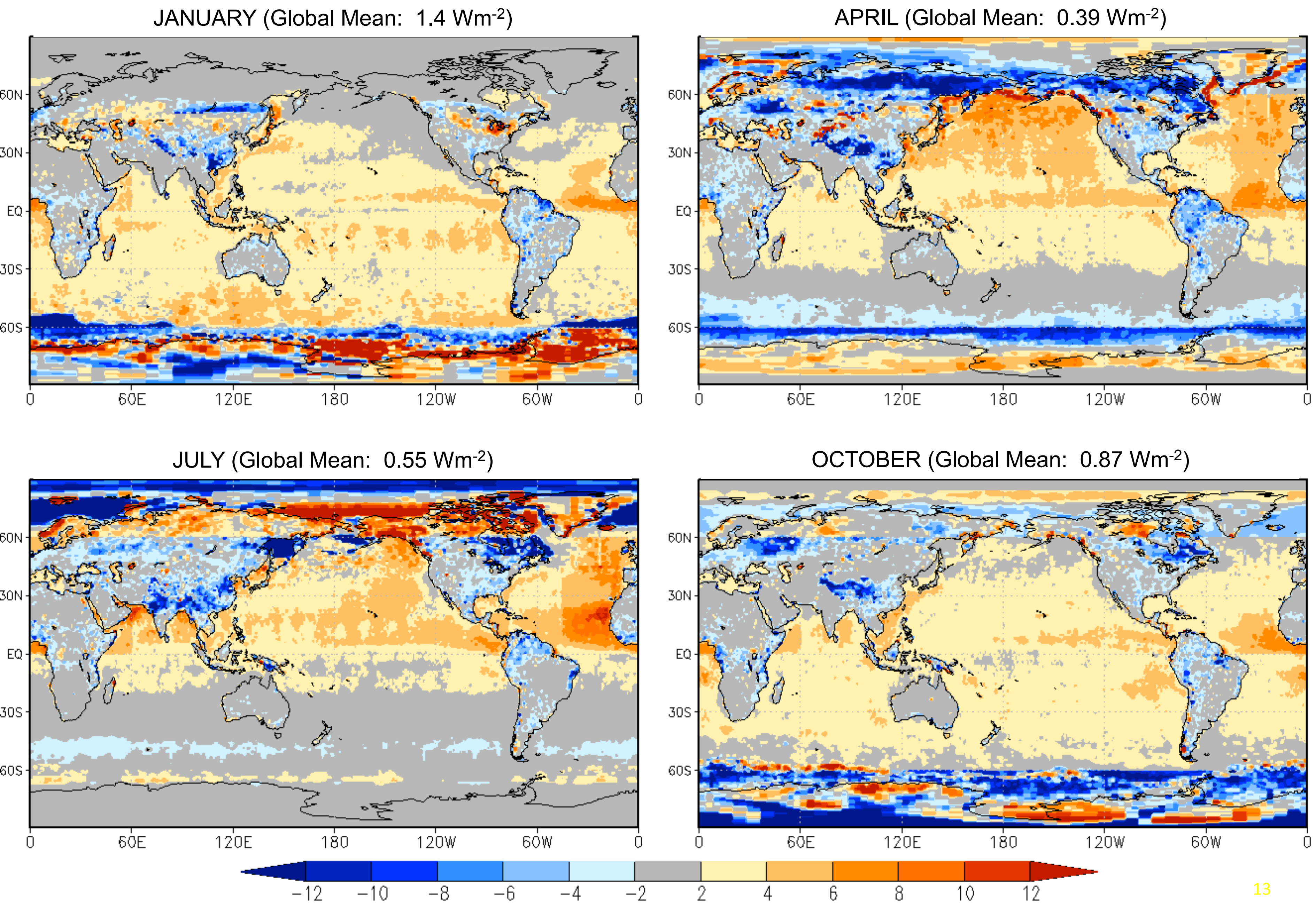
- Poor correlation between Hi-Res clear-sky LW TOA flux and clear-area fraction.

- Spread in OLR can be replicated from Fu-Liou calculations using T & q from GEOS5.

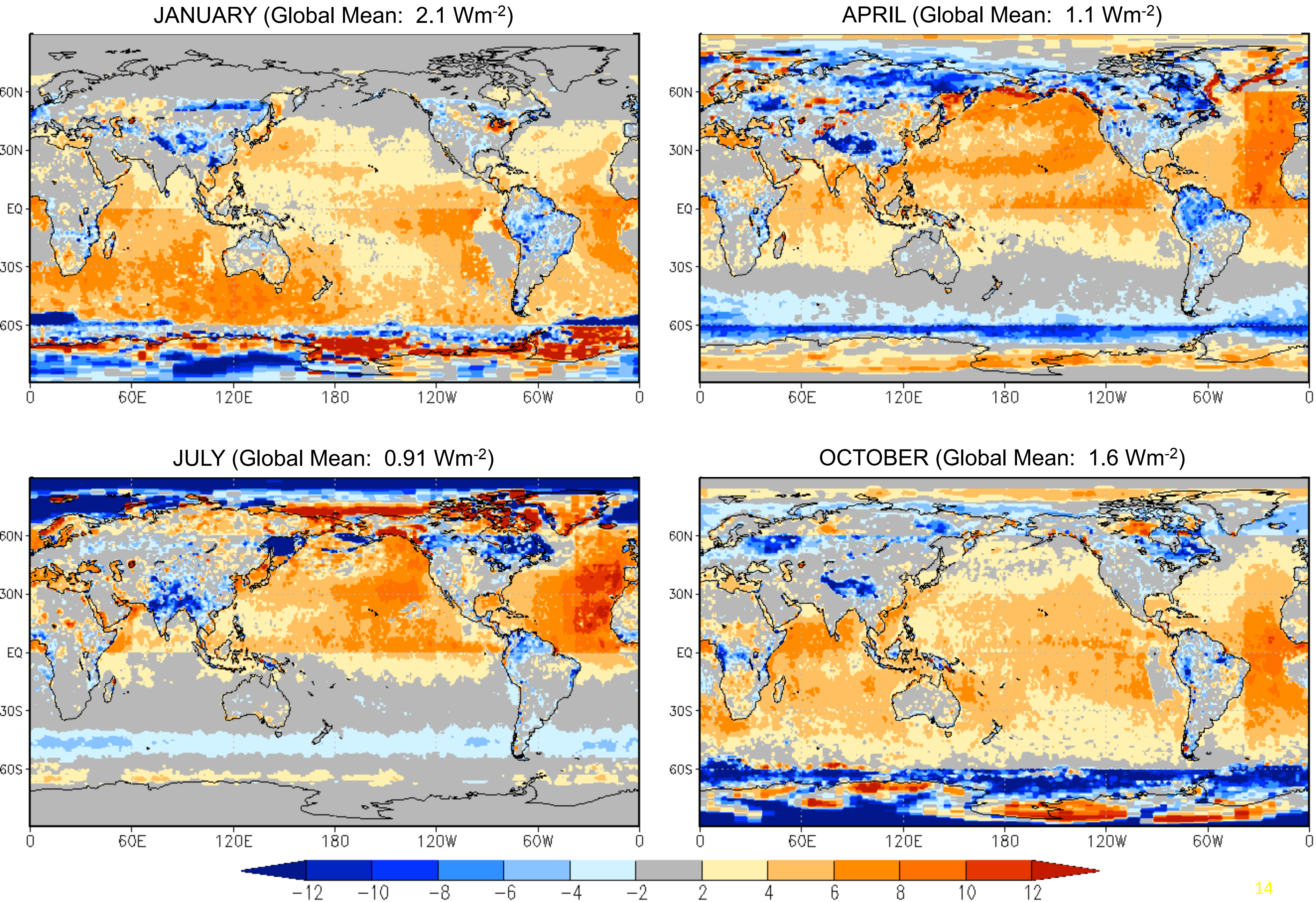
  => Clear-area weight SW clear-sky hires flux.
  => Use equal weight for LW


SW_AllSky Clim (Mar2000-Jun2015): Ed4 minus Ed2.8
JANUARY (Global Mean: -0.72 Wm-2)
APRIL (Global Mean: -0.67 Wm-2)
JULY (Global Mean: -0.36 Wm-2)
OCTOBER (Global Mean: -0.71 Wm-2)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−12
−10
−8
−6
−4
−2
2
4
6
8
10
12

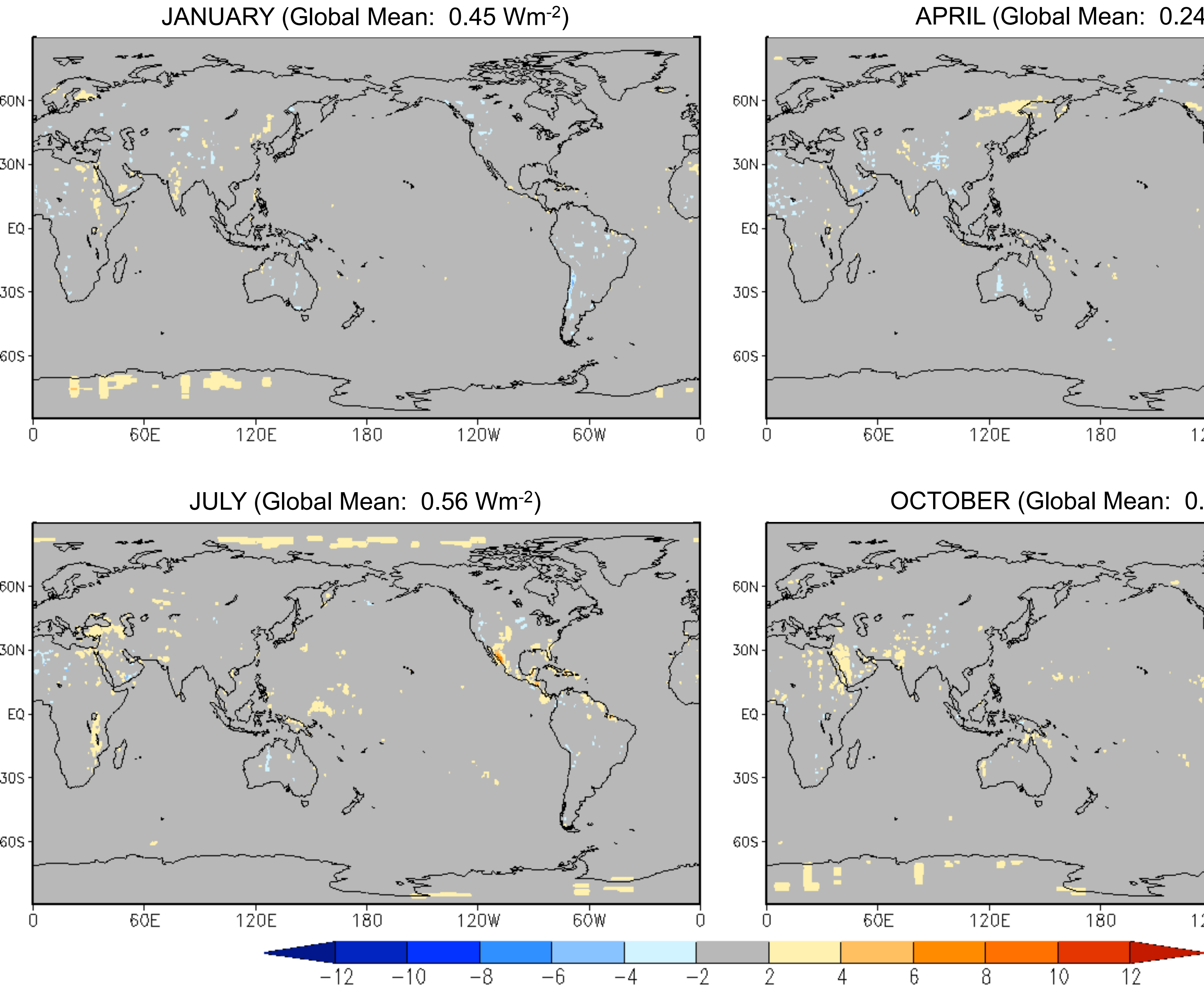
# ClrSky_SW Clim (Mar2000-Jun2015): Ed4 minus Ed2.8

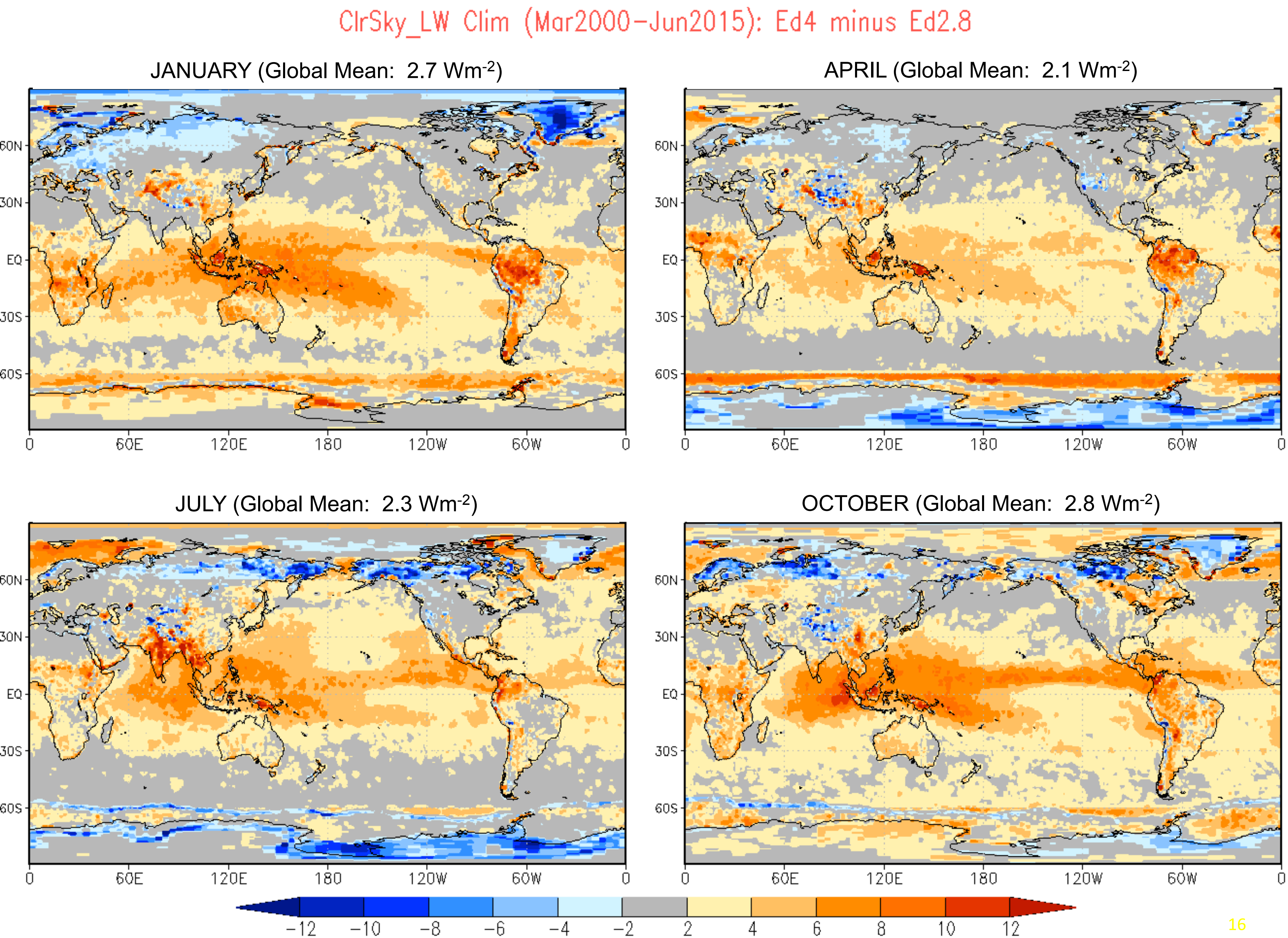


SW_CRE Clim (Mar2000-Jun2015): Ed4 minus Ed2.8

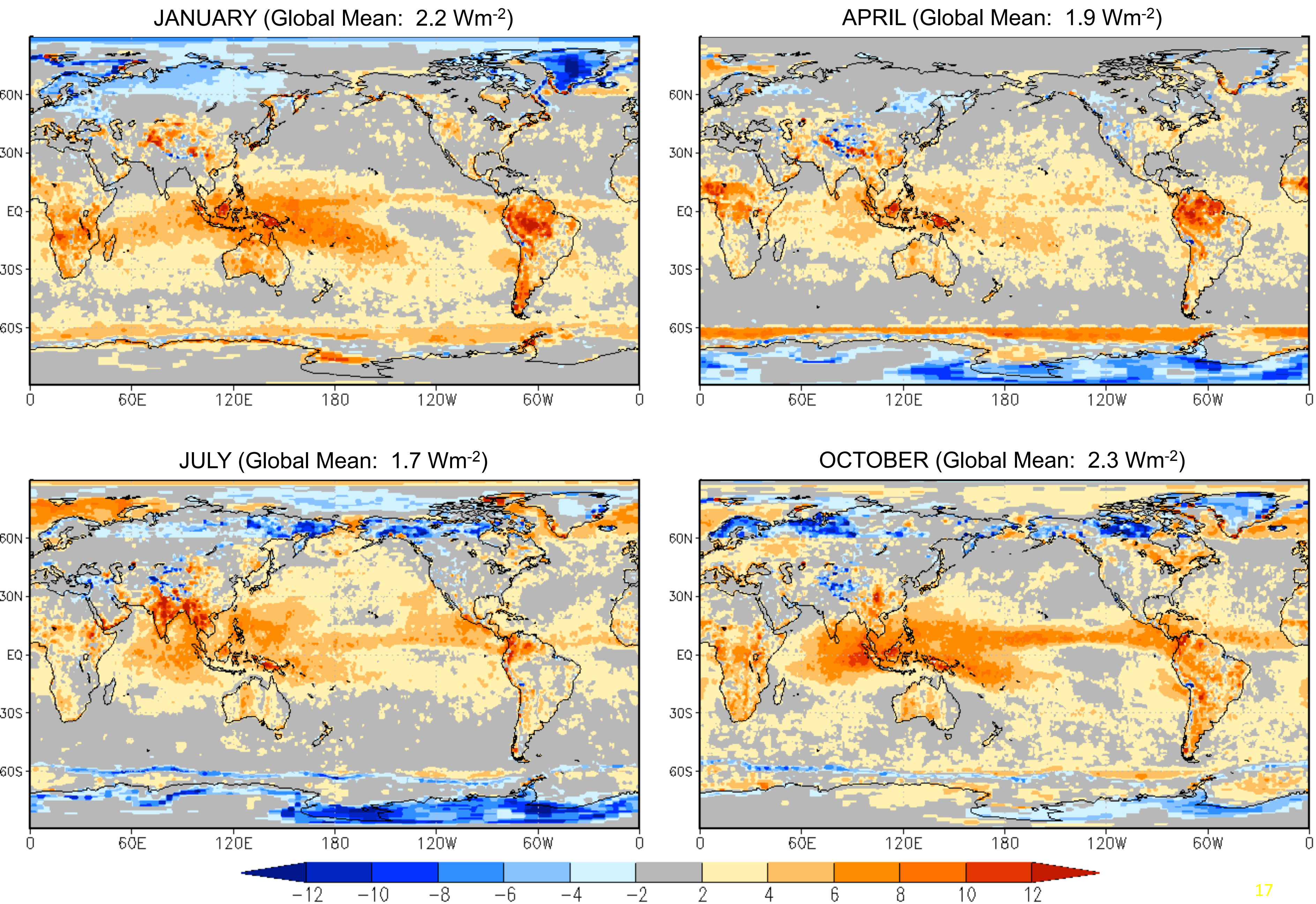


LW_AllSky Clim (Mar2000-Jun2015): Ed4 minus Ed2.8




ClrSky_LW Clim (Mar2000-Jun2015): Ed4 minus Ed2.8
JANUARY (Global Mean: 2.7 Wm-2)
APRIL (Global Mean: 2.1 Wm-2)
JULY (Global Mean: 2.3 Wm-2)
OCTOBER (Global Mean: 2.8 Wm-2)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
-12 -10 -8 -6 -4 -2 2 4 6 8 10 12

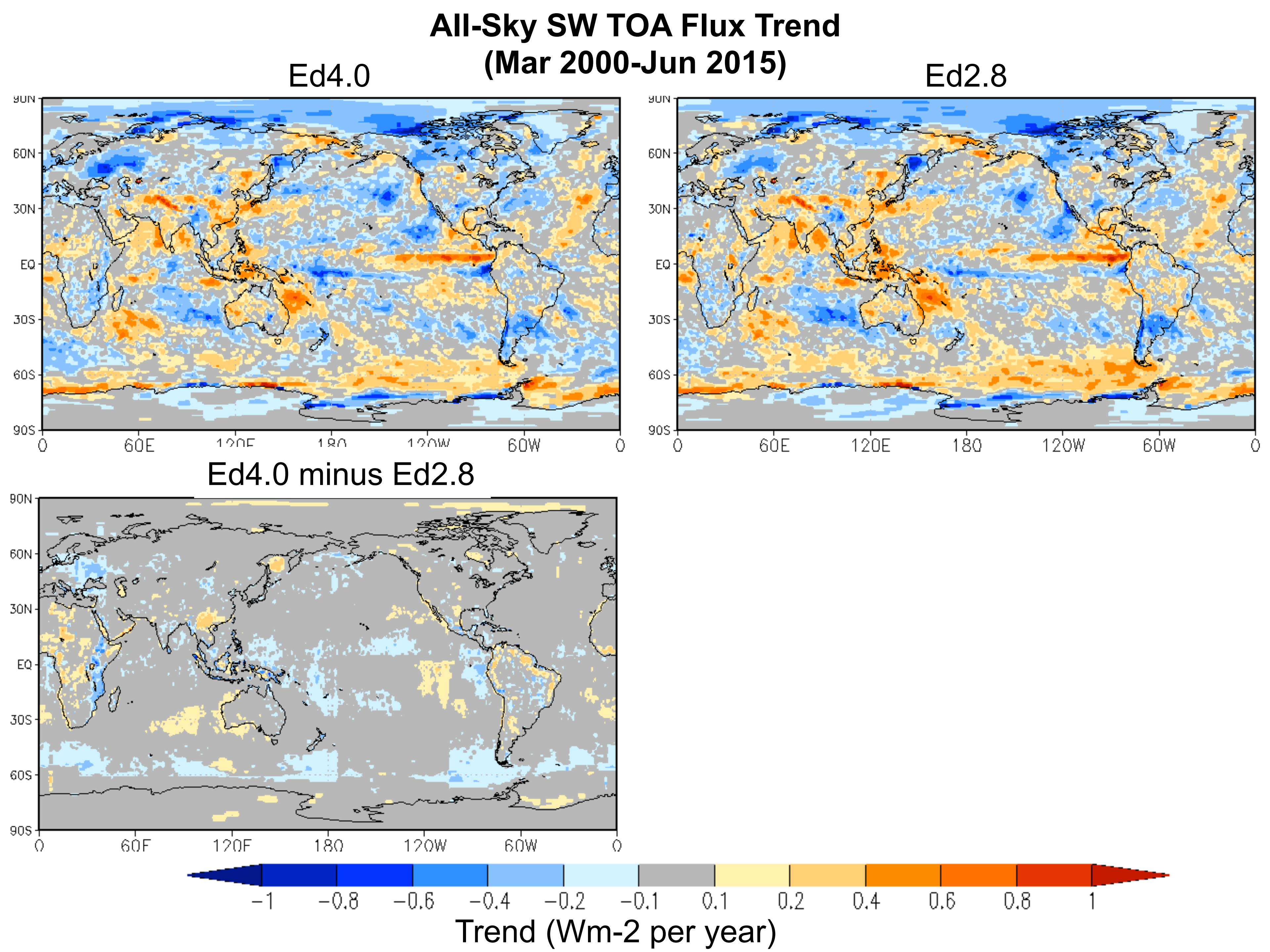
# LW_CRE Clim (Mar2000–Jun2015): Ed4 minus Ed2.8



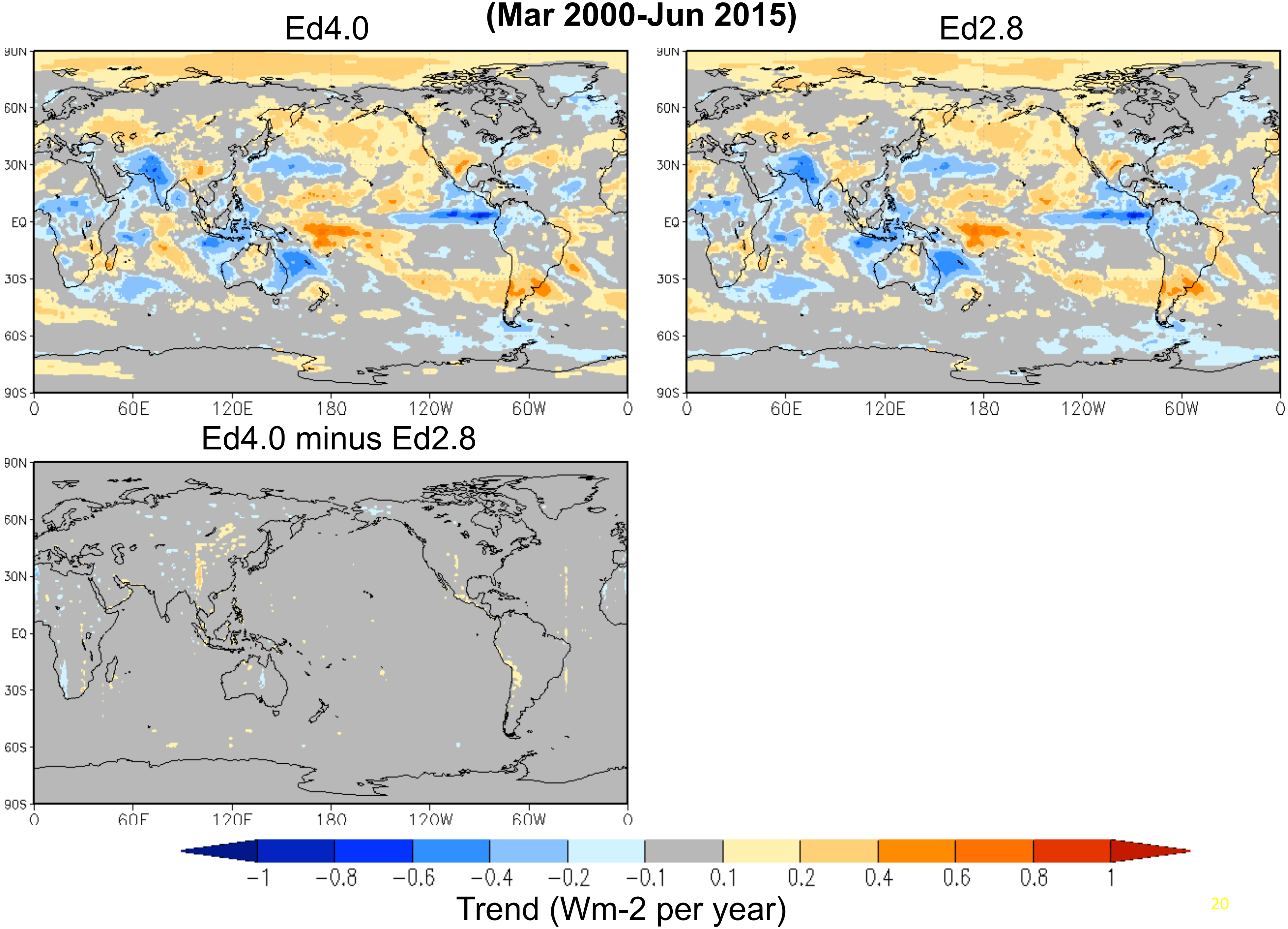
# Global Mean TOA Flux ($Wm^{-2}$) March 2000 – June 2015)

| | All-Sky | | Clear-Sky | | CRE | |
|---|---|---|---|---|---|---|
| | Ed2.8 | Ed4.0 | Ed2.8 | Ed4.0 | Ed2.8 | Ed4.0 |
| SW | 99.6 | 98.9 | 52.5 | 53.3 | -47.1 | -45.6 |
| LW | 239.6 | 240.1 | 265.6 | 268.1 | 26.0 | 28.0 |
| NET | 0.60 | 0.63 | 21.7 | 18.3 | -21.1 | -17.7 |

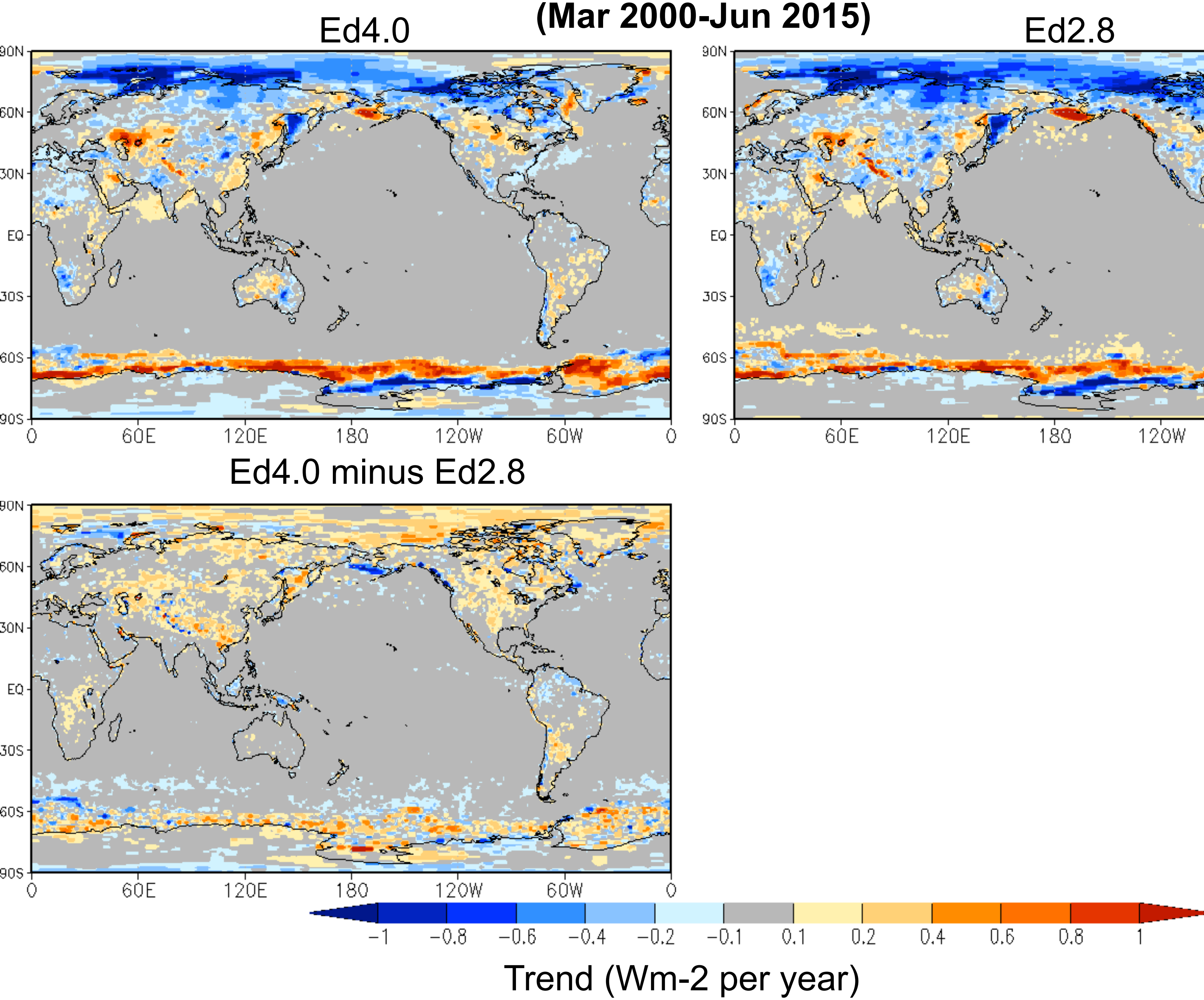
All-Sky TOA Flux Uncertainties ($1\sigma$):
SW: $\pm$ 1 $Wm^{-2}$
LW: $\pm$ 2 $Wm^{-2}$


All-Sky SW TOA Flux Trend
(Mar 2000-Jun 2015)
Ed4.0
Ed2.8
Ed4.0 minus Ed2.8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
-1
-0.8
-0.6
-0.4
-0.2
-0.1
0.1
0.2
0.4
0.6
0.8
1
Trend (Wm-2 per year)

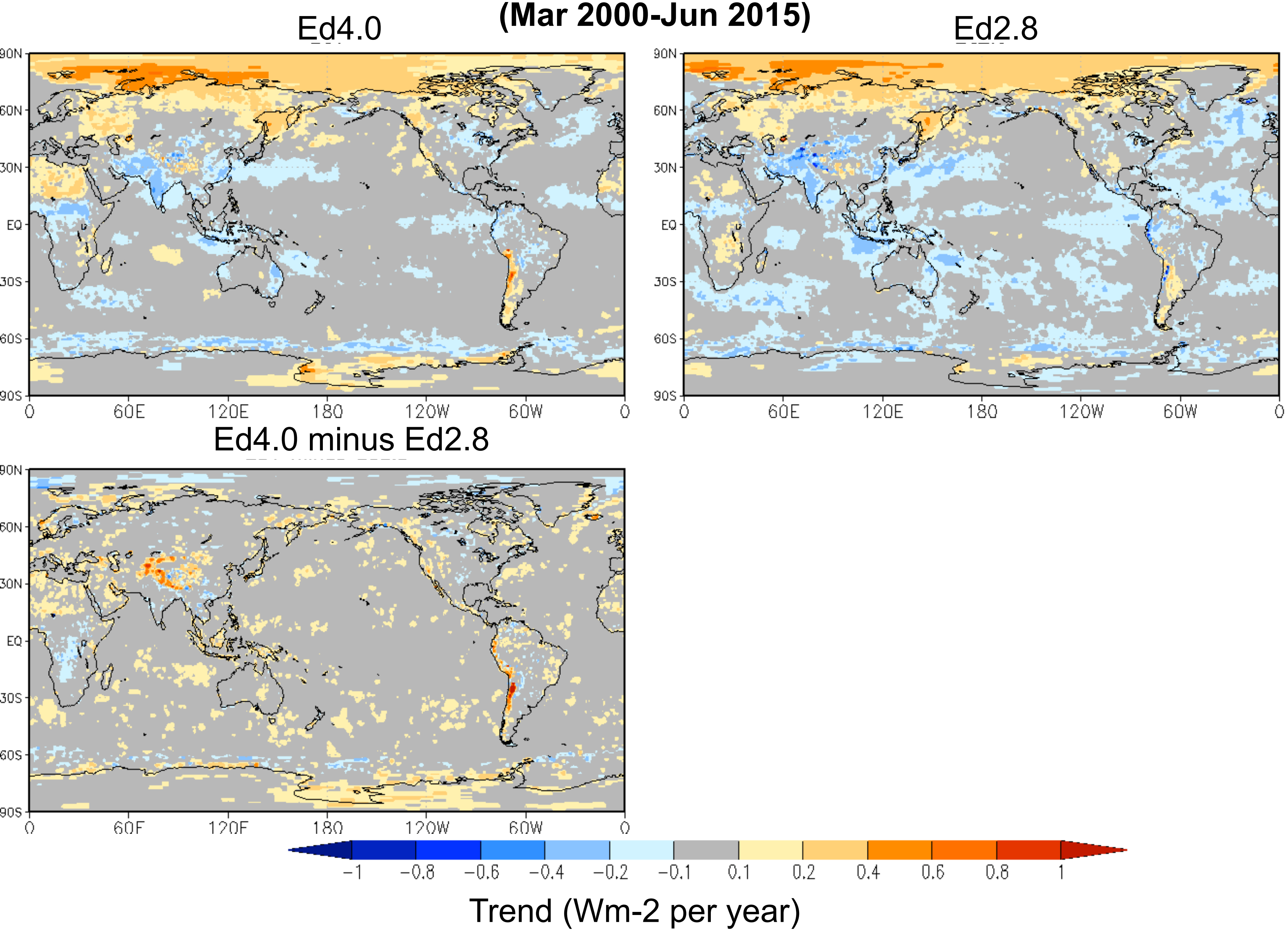
# All-Sky LW TOA Flux Trend
# (Mar 2000-Jun 2015)



# Clear-Sky SW TOA Flux Trend
# (Mar 2000-Jun 2015)



# Clear-Sky LW TOA Flux Trend
# (Mar 2000-Jun 2015)



# Global Mean TOA Flux Trends ($Wm^{-2}$per decade) (March 2000 – June 2015)

| | All-Sky | | Clear-Sky | | CRE | |
|---|---|---|---|---|---|---|
| | Ed2.8 | Ed4.0 | Ed2.8 | Ed4.0 | Ed2.8 | Ed4.0 |
| SW | -0.11 | -0.40 | -0.19 | -0.31 | -0.075 | 0.097 |
| LW | -0.017 | 0.090 | -0.55 | -0.20 | -0.53 | -0.29 |
| NET | 0.091 | 0.27 | 0.70 | 0.47 | -0.61 | -0.20 |

Slope 95% Conf. Intvl: ~0.1 to 0.2 $Wm^{-2}$ $decade^{-1}$

# Summary

- EBAF Ed4 incorporates the many improvements that are part of the Edition 4 suite of CERES data products (Level 1-3).
- All-sky TOA flux differences will be relatively minor compared to Ed2.8.
  - EEI constraint will be based upon new 10-year Argo estimate.
- EBAF Ed4 Clear-sky TOA fluxes differ markedly from Ed2.8:
  - Global annual mean SW TOA flux increases by 0.8 $Wm^{-2}$
  - Global annual mean LW TOA flux increases by 2.5 $Wm^{-2}$
- EBAF Ed4 trends are within 0.3 Wm-2 per decade of Ed2.8.
  - Large reduction in LW clear-sky trend owing to consistent reanalysis (GEOS 5.4.1) throughout record.
- Anticipated EBAF Ed4 release: January 2017.